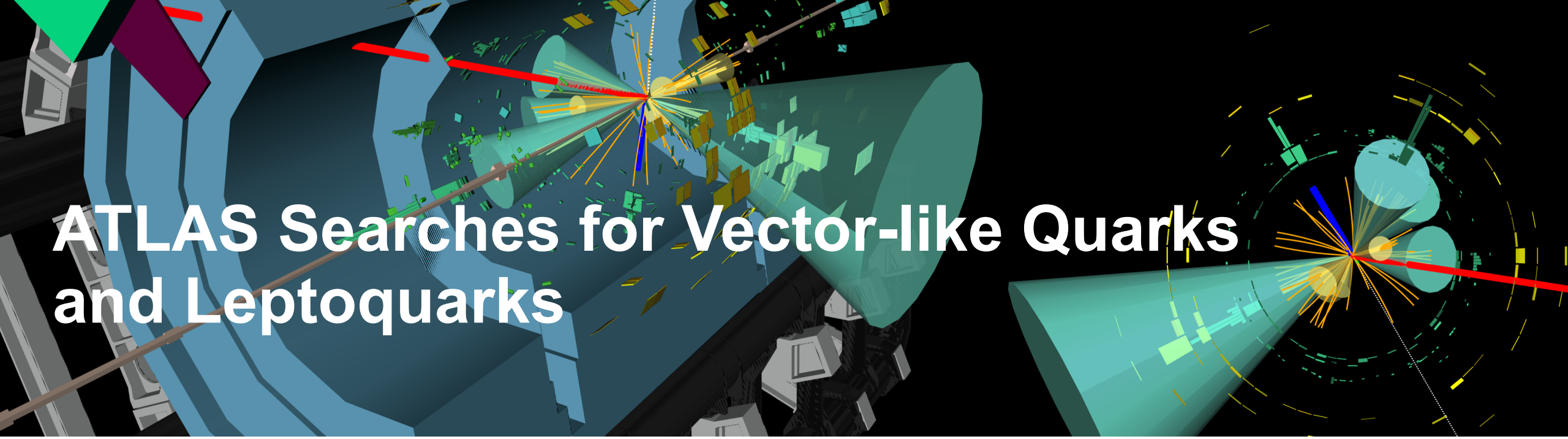


ATLAS Searches for Vector-like Quarks and Leptoquarks

Krisztian Peters (DESY)
On behalf of the ATLAS Collaboration

ICHEP, Prague, 20.07.2024

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

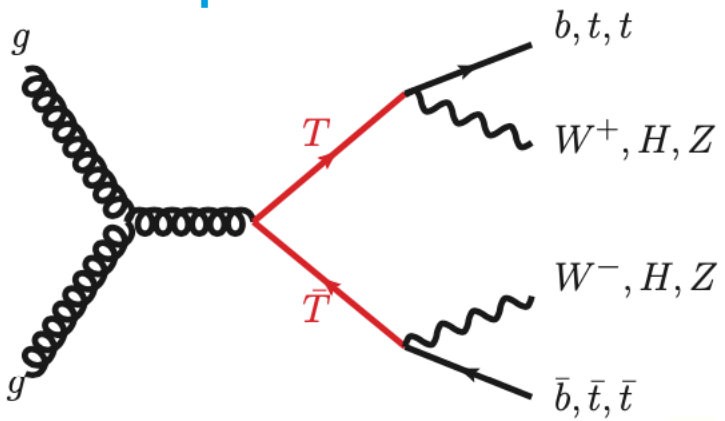
VLQ searches in a nutshell

Overview and motivation

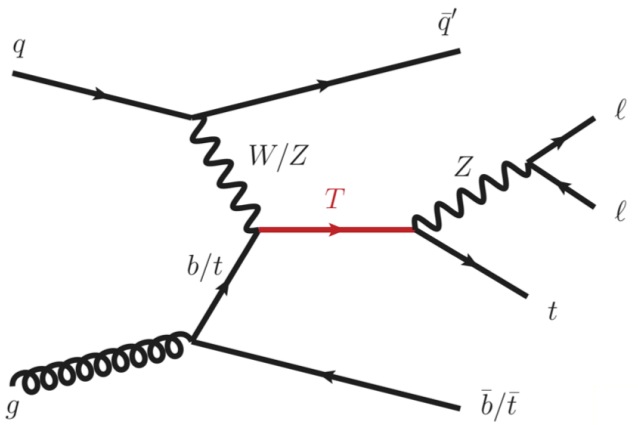
Color triplet spin-1/2 fermions with equal right- and left-handed SU(2) chiral transformations

- Common in many BSM theories, particularly in strongly-coupled composite Higgs theories
- Could mitigate Higgs mass fine-tuning, hence focus so far on **decay to 3rd gen. quarks**

Pair production



Single production



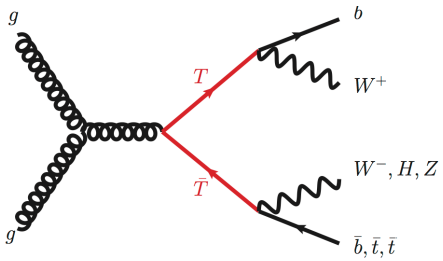
Decays of SU(2) singlet and doublet

		Decays
Singlet	T	$T \to bW^+, tZ, tH$
	B	$B \to tW^-, bZ, bH$
Doublet	(T, B)	$T \to tZ, tH, B \to bW^-$
	(X, T)	$X \to tW^+, T \to tZ, tH,$
	(B, Y)	$B \to bZ, bH, Y \to bW^-$

Complex final state, **H/W/Z/top/b tagging** and **S_T important discriminants** against backgrounds. Analysis channels defined by detector signature (typically number of jets and leptons or large E_T^{miss})

Vector-like quarks

Search for pair-production of vector-like quarks in lepton+jets final states containing at least one b-tagged jet using the Run 2 data from the ATLAS experiment



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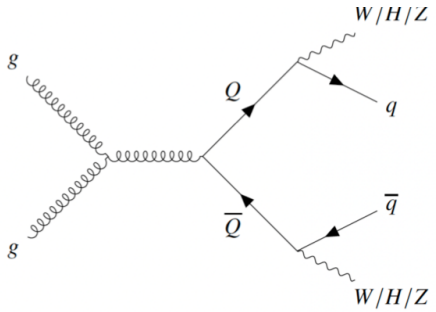
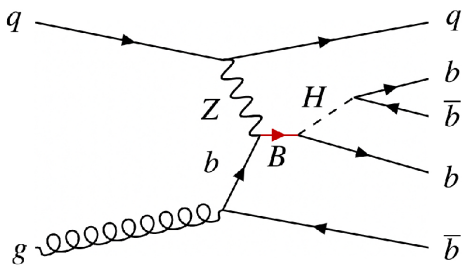
Search for pair-produced vector-like quarks coupling to light quarks in the lepton plus jets final state using 13 TeV pp collisions with the ATLAS detector



Search for single vector-like B quark production and decay via $B \to bH(b\bar{b})$ in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector



VLQ pair production with lepton+jets and b-jets

Main target $TT \rightarrow WbWb$ (but also sensitive to other VLQs and decay modes)

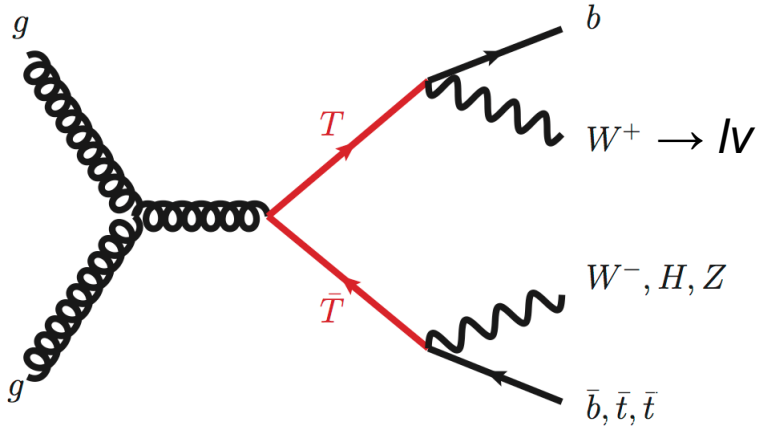
Optimised for *T* decay to a *W* and *b*-quark

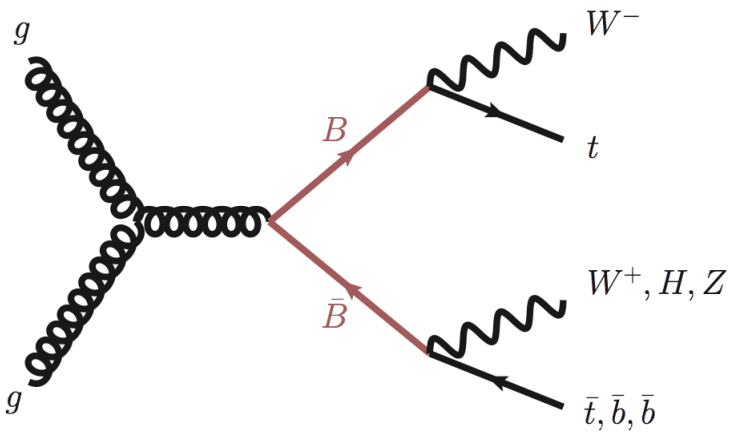
- One *W* decays to *e/μ*, the other hadronically
- Suppress with *e/μ* selection hadronic backgrounds
- Large *W* to had. BR for second VLQ decay

Event signature and selection (focus on *T*-quark masses above 1.3 TeV)

- One high-p_T *e* or *μ* and large E_T^{miss}
- *W*-tagged large-R jet
- Multiple small-R jets, at least one *b*-tagged

Reconstructed mass of leptonic *T* decay used for final signal extraction





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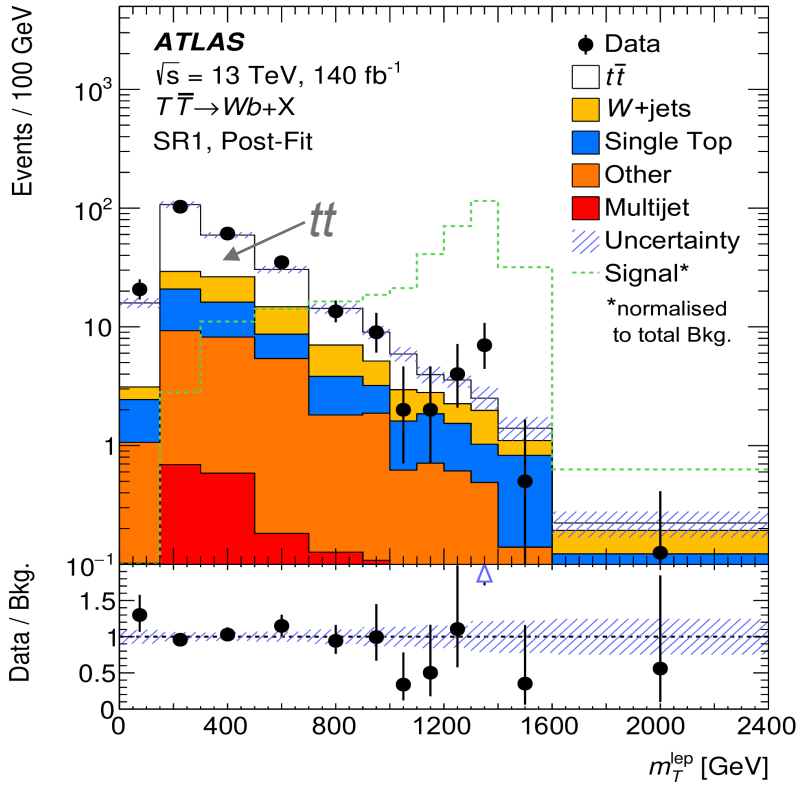
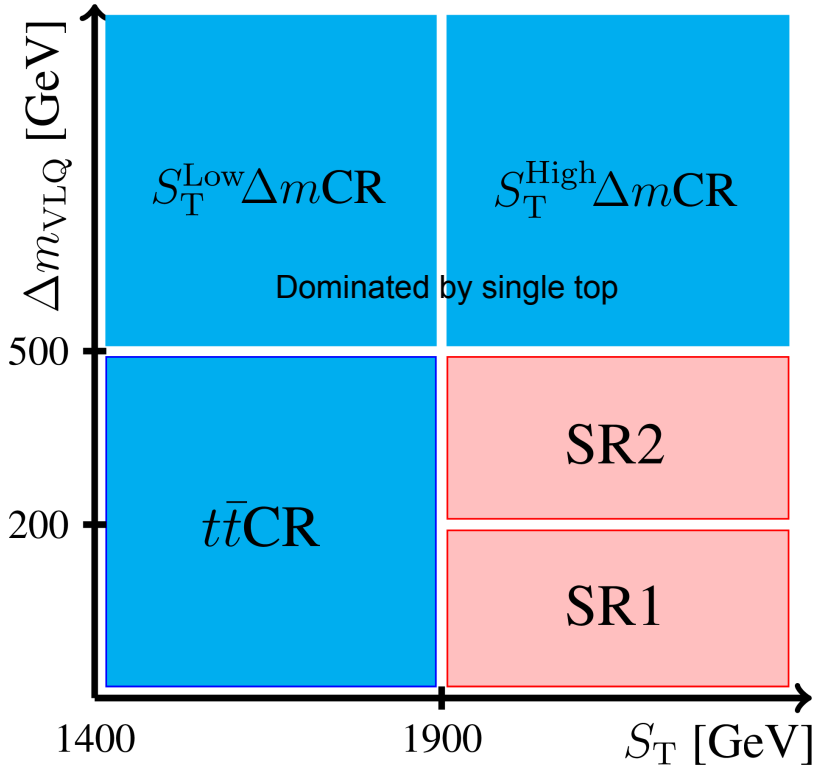
Analysis strategy for the *Wb+X* final state

Main backgrounds and data-driven corrections

Pair small-R jets with *W* boson candidates such that **difference** between **two *T*-quark masses minimised**

Additional **W+jets** and **tt** reweighing regions for **data driven corrections**

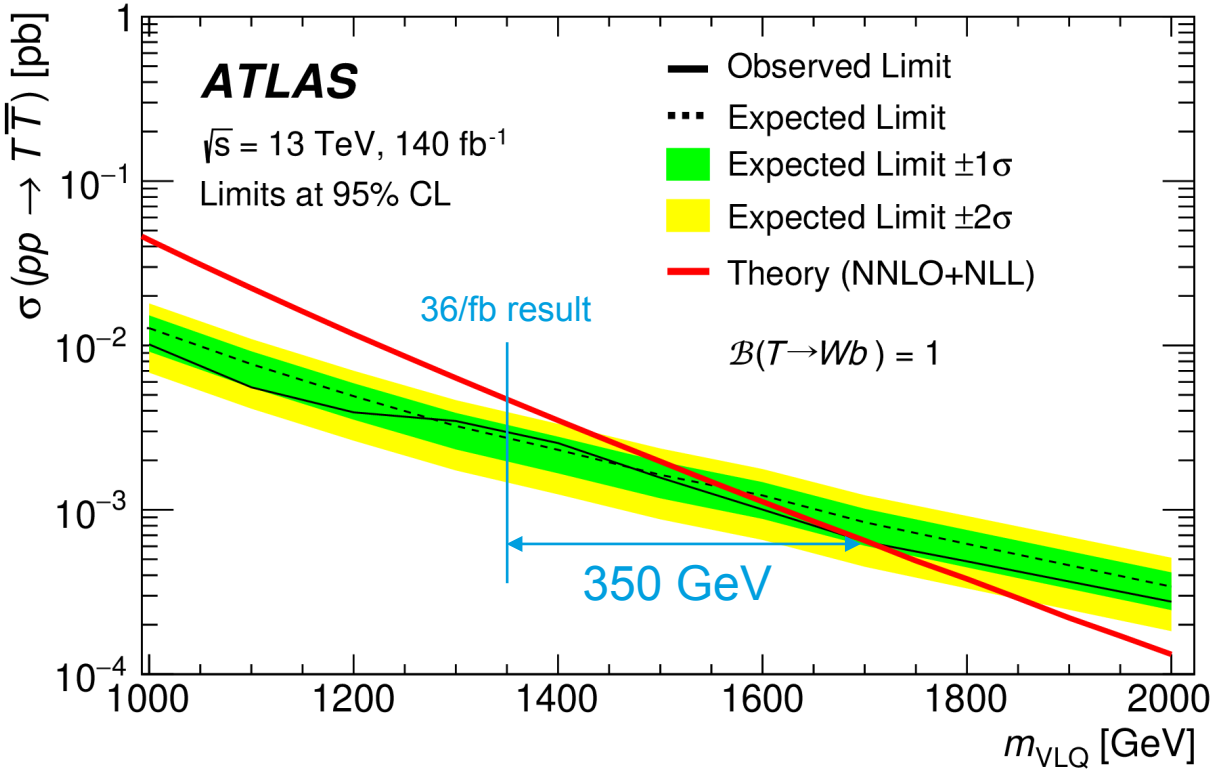


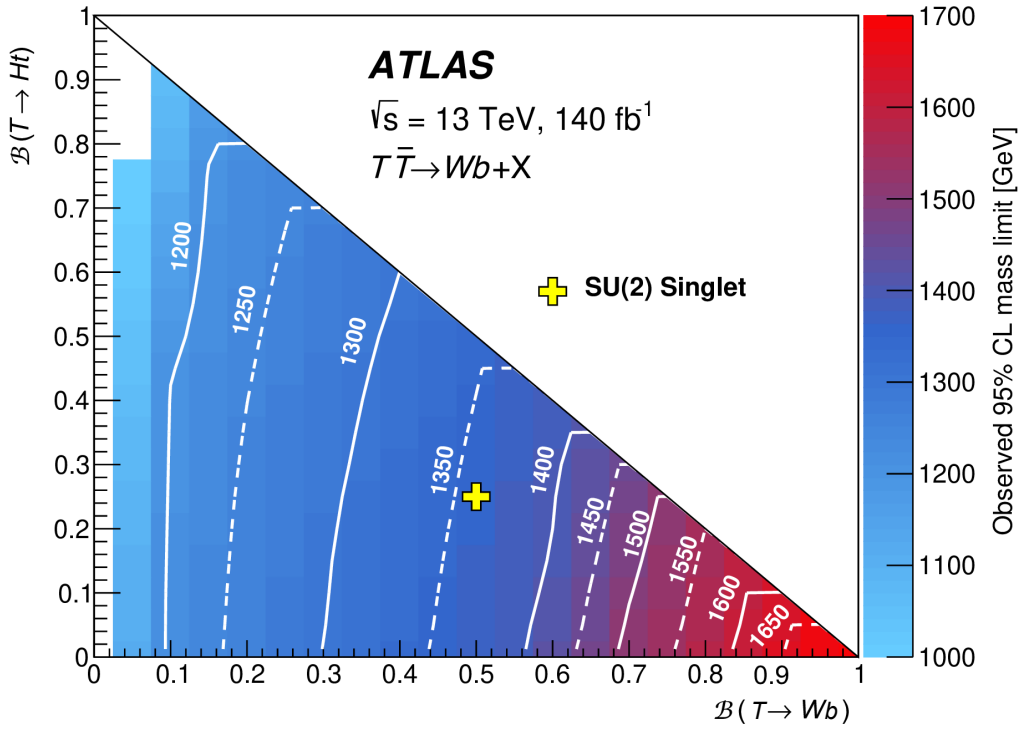


Presence of VLQ signal is tested with a simultaneous fit in these regions

Significantly improved limits

Dominated by statistical uncertainty





Larger data set and **20% improvement** from slicing into **SR1/SR2**, improved ***W*-boson tagging**

Test other BRs with the requirement **B($T \to Wb$) + B($T \to Ht$) + B($T \to Zt$) = 1**

Although designed for *TT*, also **sensitive for *BB* production** with similar exclusion plots

VLQ pair production coupling to light quarks

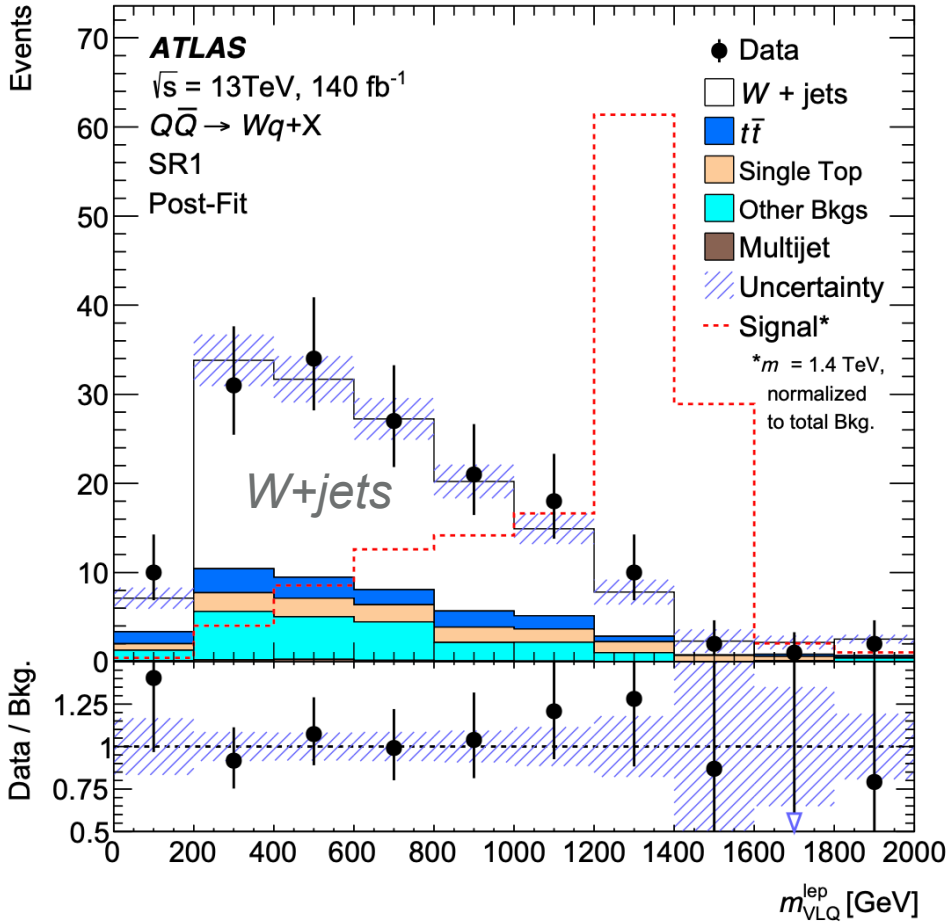
Main target *TT→WqWq* (one *W* decays to *e/μ*, the other hadronically)

Predicted by various **BSM models** with extended symmetries, **not** directly motivated by **hierarchy problem**

Similar event selection and **analysis strategy** to *Wb+X* final state search, yet **no b-jet tagging**

Two signal regions separated with $\Delta\phi$ cut at 2.75 between lead jet and E_T^{miss}

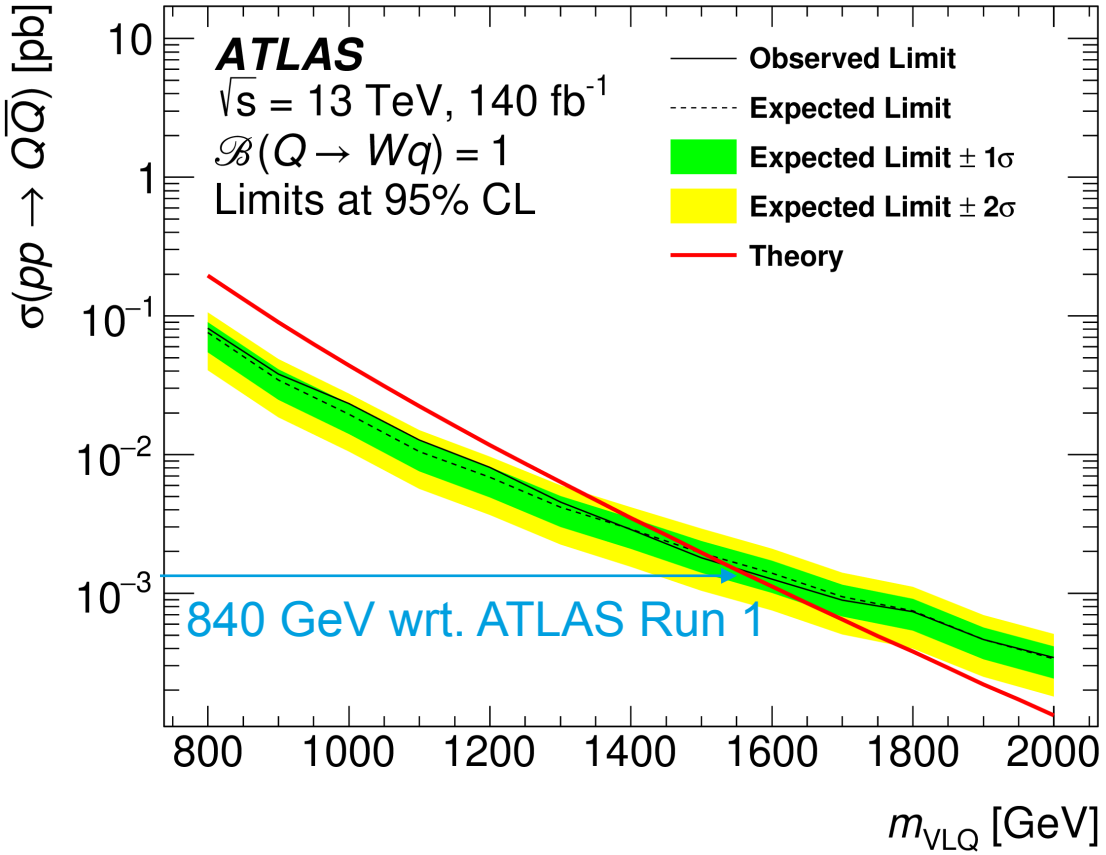
Only **signal regions** included in the **likelihood fit,** CRs used to validate background modelling, which are corrected in reweighing regions

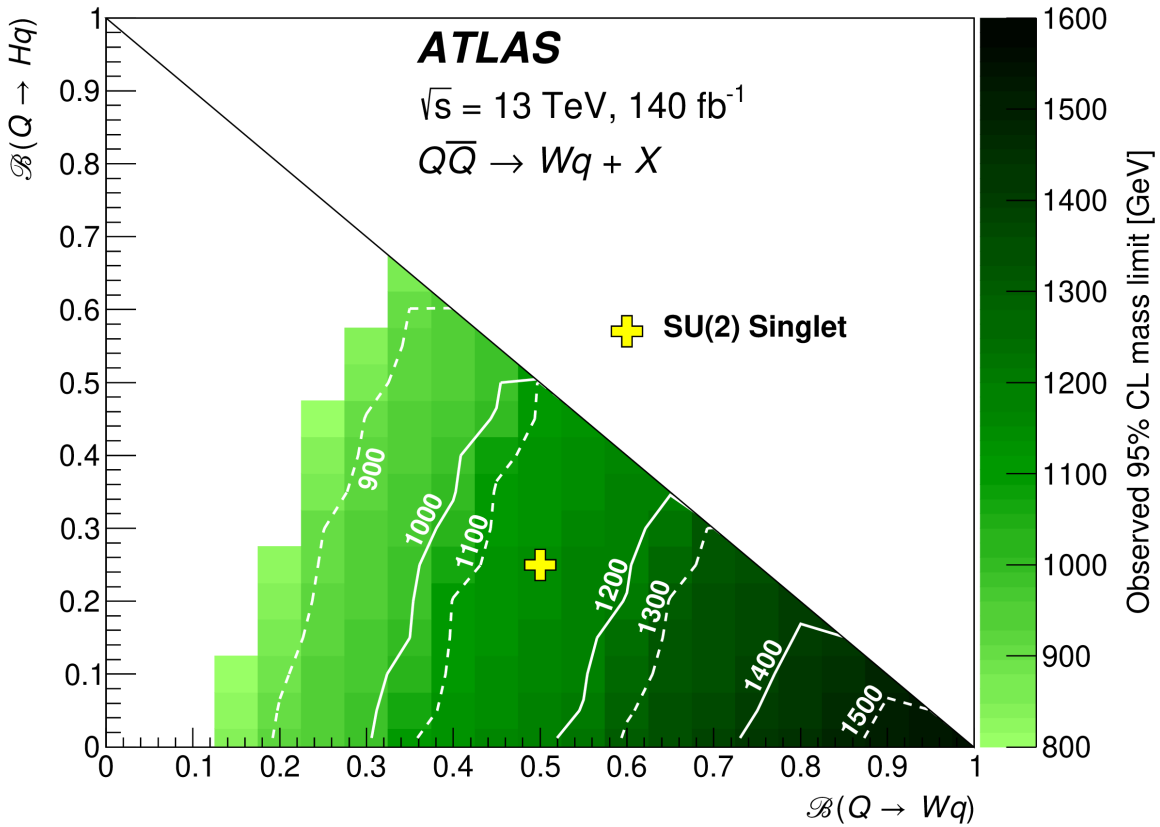


arXiv:2405.19862 Submitted to Phys. Rev. D.

First LHC Run 2 search for VLQ with light quark decays

Strong improvement on latest (Run 1) limits





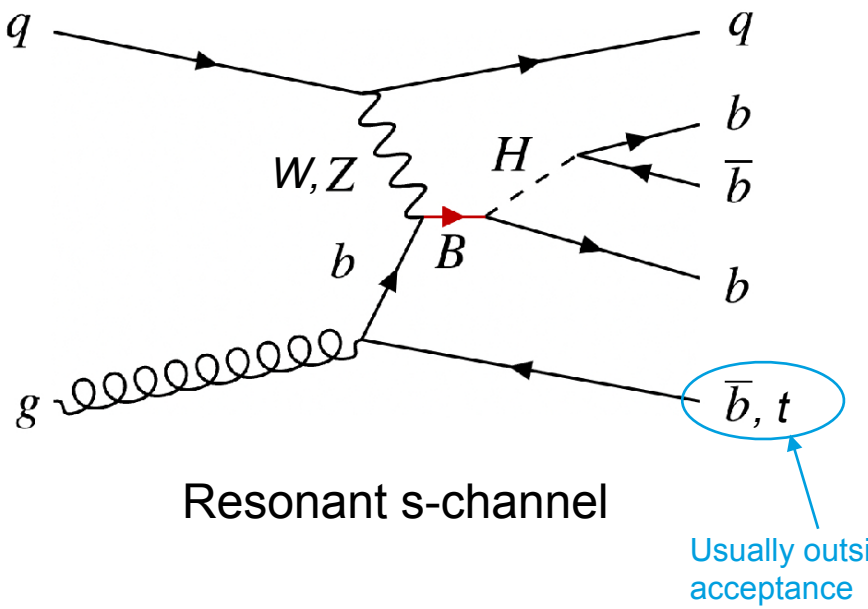
Test other BRs with the requirement **B($Q \to Wq$) + B($Q \to Hq$) + B($Q \to Zq$) = 1**

Single VLB production with decay to b-quarks

Main target $B \rightarrow bH(bb)$, dominant at high masses (pair production reach to ~1.2 TeV)

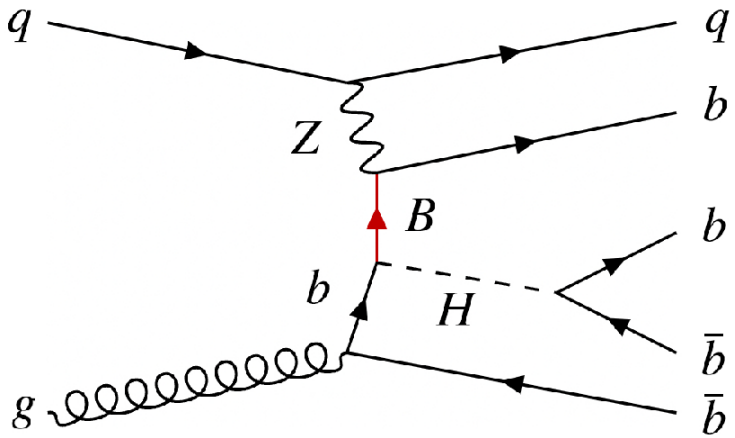
Coupling between VLB quarks and *W,Z,H* bosons regulate the production XS and decay width

Different coupling ratios for multiplet scenarios, but all scale with the universal coupling strength κ

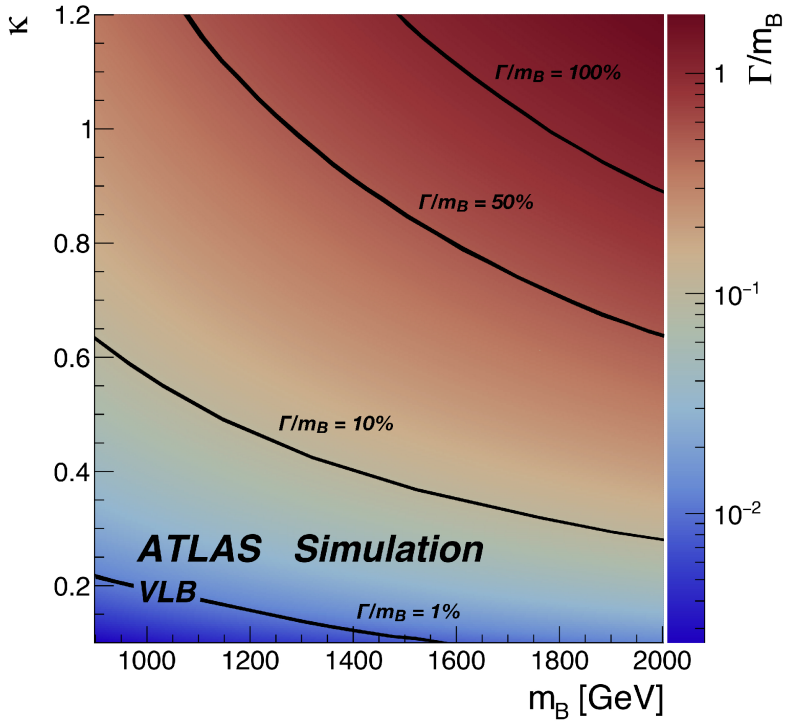


Resonant s-channel

Usually outside acceptance

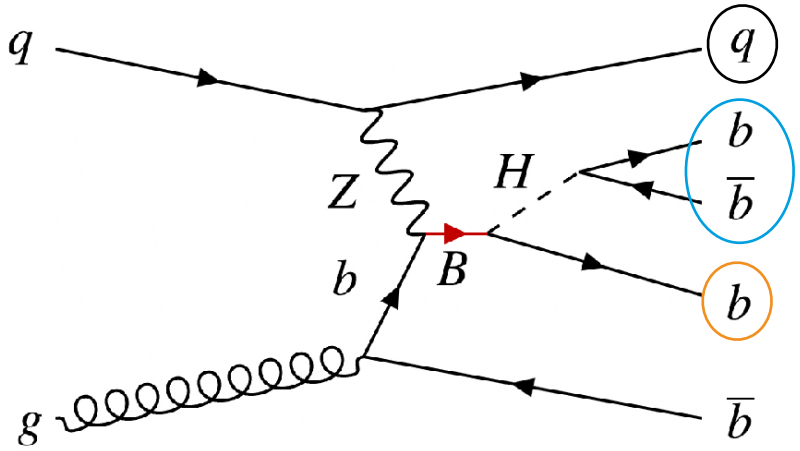


Non-resonant t-channel



Analysis strategy for the *bH(bb)* final state

Multijet production overwhelming background, data-driven estimate



Jet in the forward region

Large-R jet, containing two b-tagged track jets

B-tagged small-R jet, opposite to large-R jet, both high pT (> 400/480 GeV)

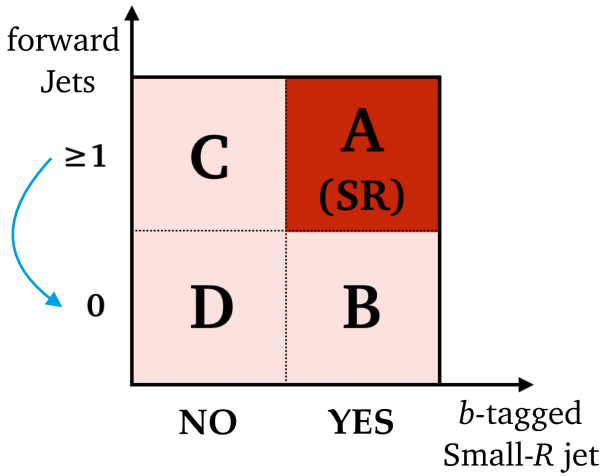
} VLB mass for signal extraction

+Additional QCD multi-jet rejection cuts

SR defined with a tight requirement on the Higgs candidate mass

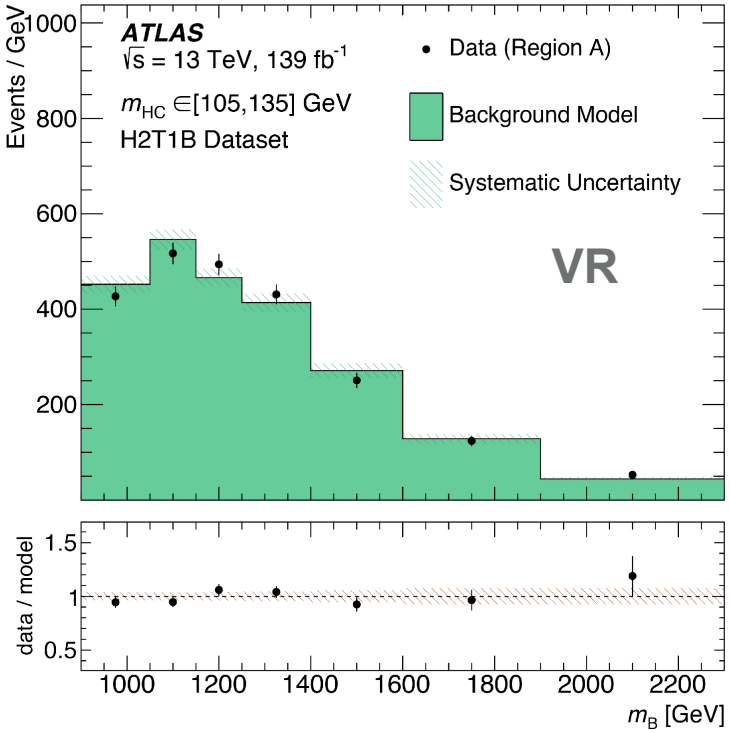
- Per-cent level signal efficiency due to tight kinematic selection (e.g. large-R jet pT and tripple b-tag)

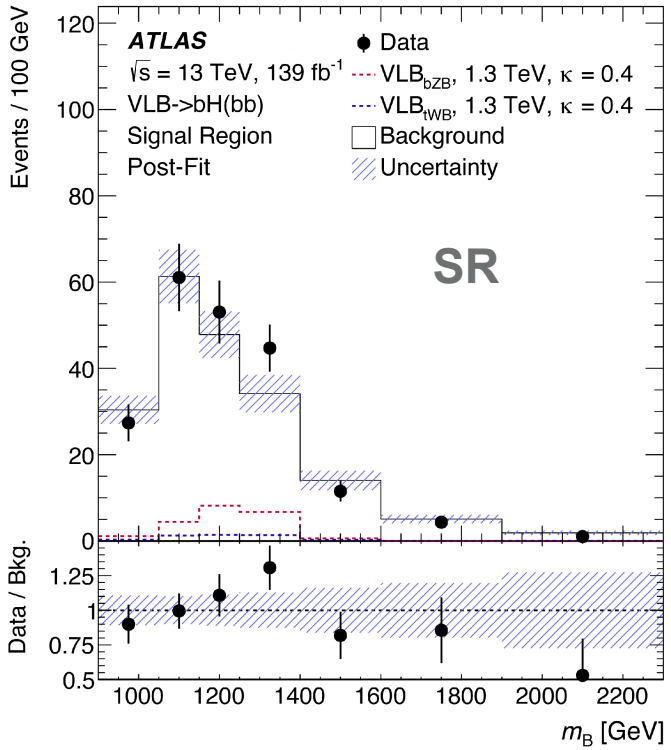
SR-like categories with 1 b-tagged track jet in large-R jet and/or outside Higgs mass range are used to correct and validate background model



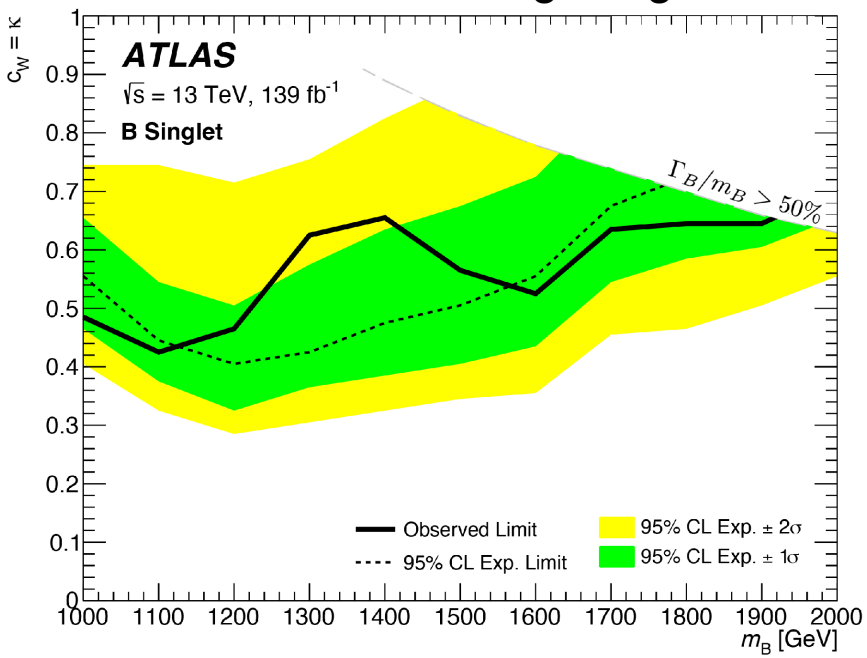
Results for single VLB production

Increase mass reach up to 2 TeV





Exclusion limits on couplings for various scenarios, e.g. singlet



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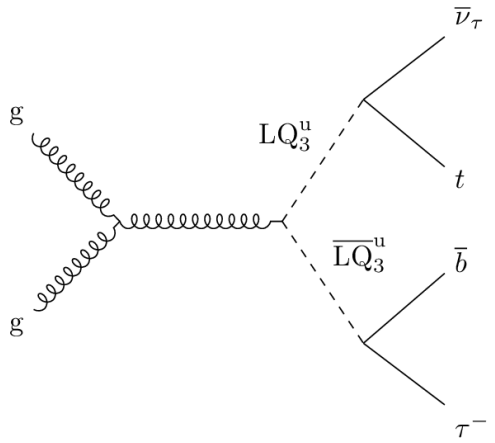
Uncertainties from ABCD residual correlation and shape correction have largest impact on sensitivity

Leptoquarks

Combination of searches for pair-produced leptoquarks at $\sqrt{s} = 13$ TeV with the ATLAS detector



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Leptoquark searches

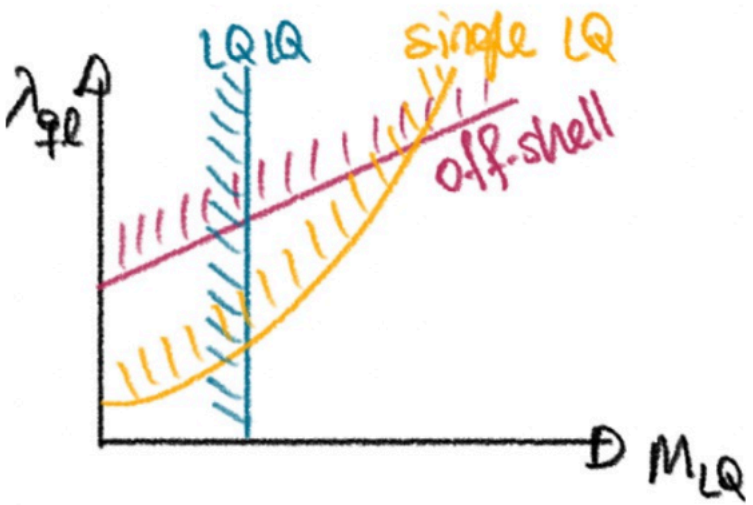
With decays to 3rd gen. Quarks

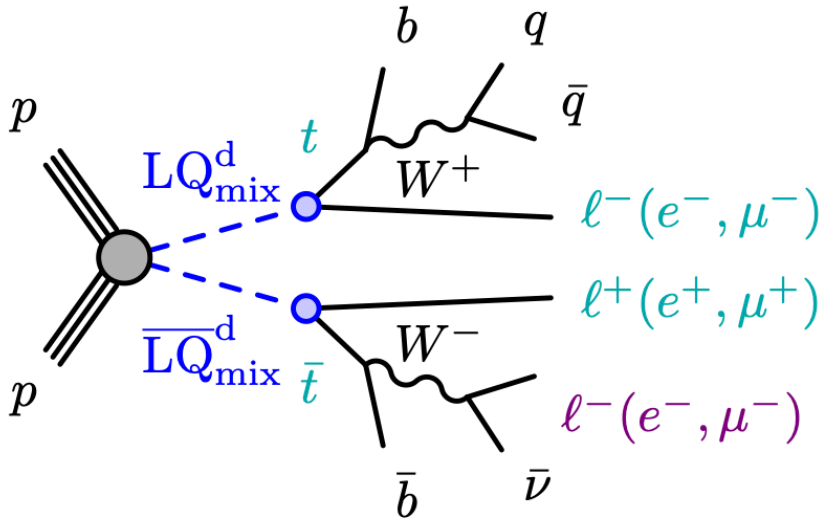
LQs couple simultaneously to **quarks and leptons** and may explain recent B-meson anomalies or muon $(g-2)$

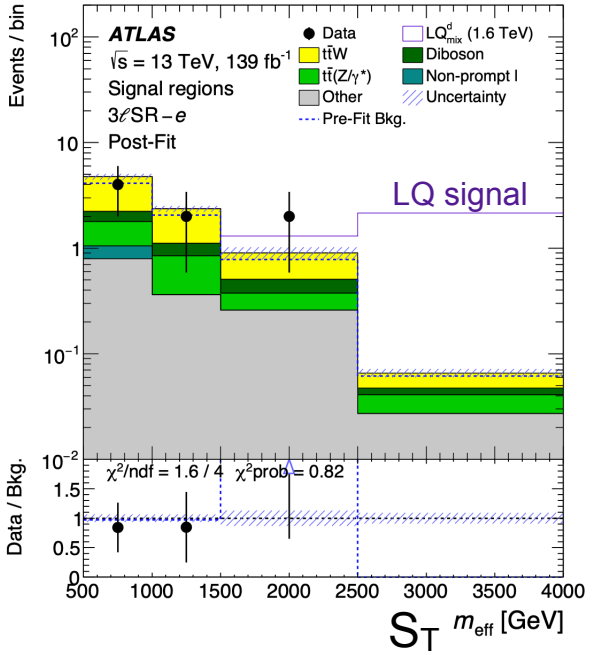
Either scalar or vector particles, have fractional charge and carry color, B and L quantum numbers

Scalar **pair production** cross section **depends only on LQ mass**, **sensitivity to lower couplings and masses**

Similar analysis concepts to VLQ searches. Results primarily limited by **statistical uncertainties**







Combination of pair-produced LQ searches

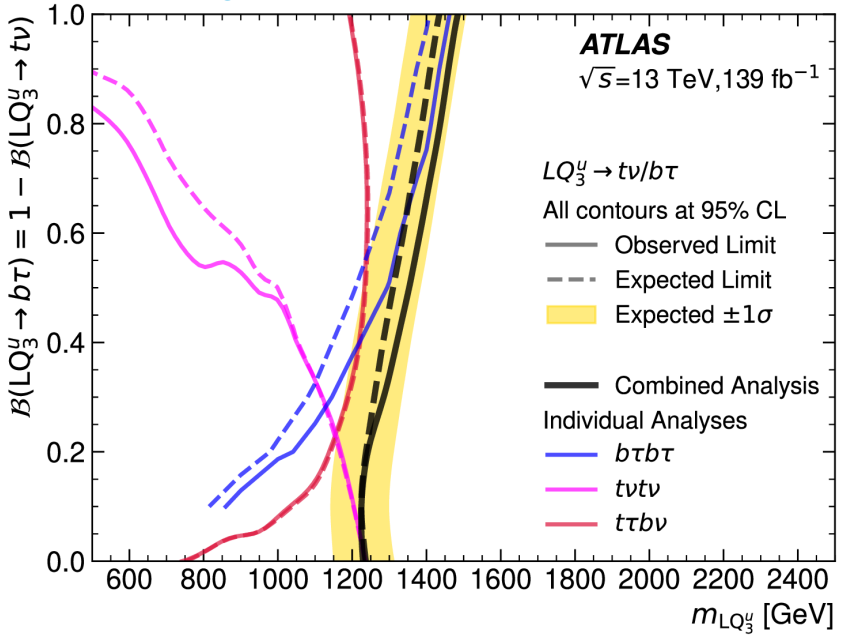
9 independent searches with decay to 3rd gen. quarks and leptons of all generations

Sets of these analyses are **combined** for exclusions limits on **3rd gen.** and **mixed scalar LQs**

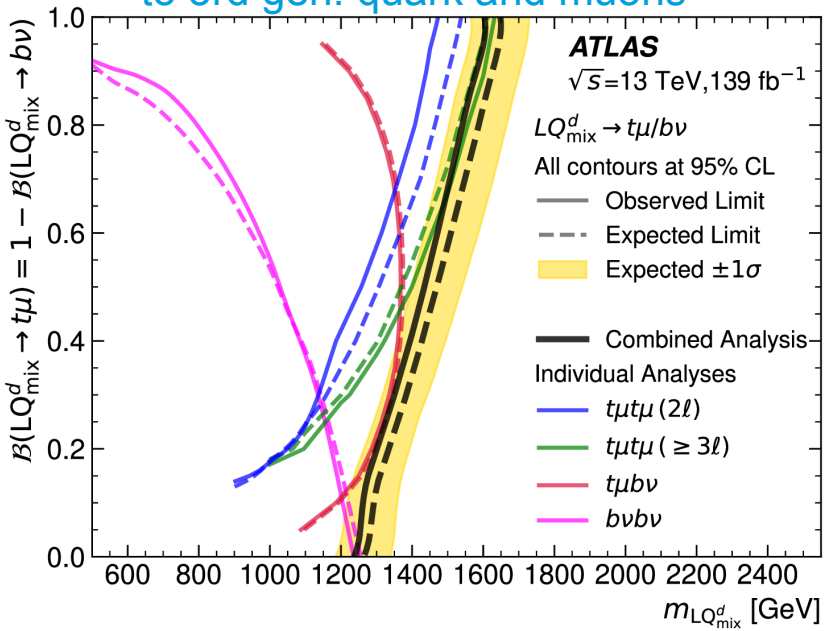
Orthogonality given through **lepton selection** requirements, residual overlap has negligible impact

Channels sensitive in **complementary regions, improved exclusion** range for most BR values

Up-type scalar LQs decaying to 3rd gen. quark and lepton



Down-type scalar LQs decaying to 3rd gen. quark and muons



6 such combinations

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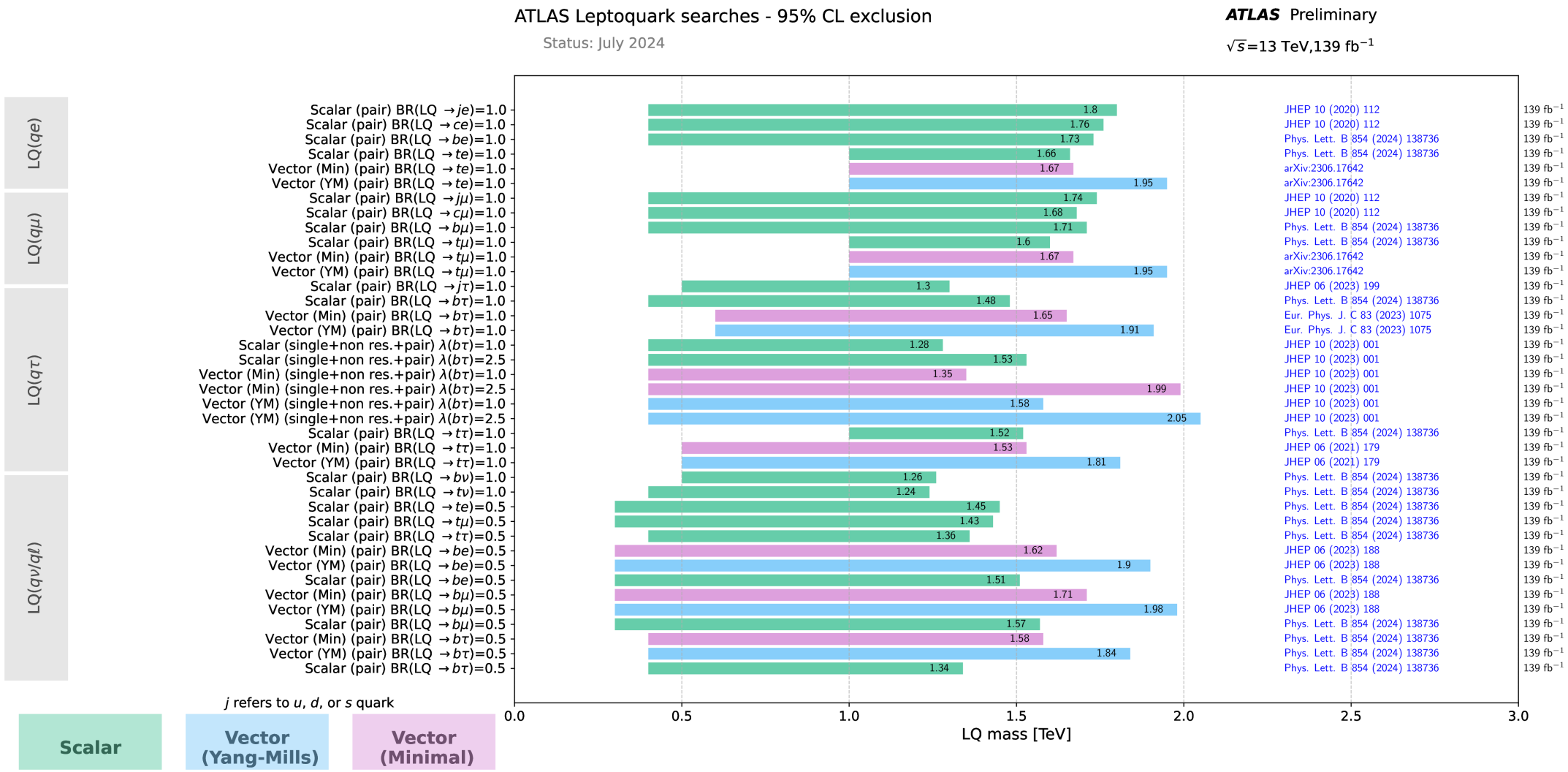
Overview of ATLAS LQ results

Different LQ models and production modes, decays to all lepton generations explored



Conclusions

ATLAS searches for VLQs and LQs

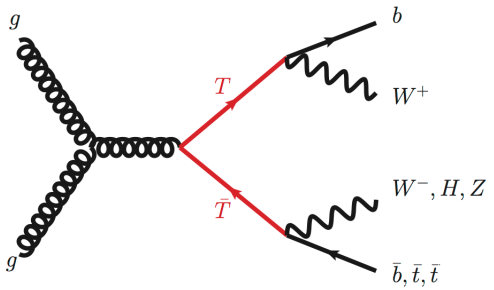
A very **broad programme**, yet no evidence for new phenomena so far

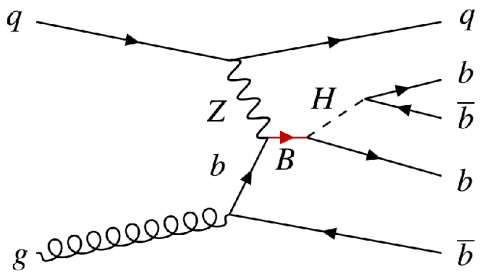
New ATLAS results on **pair** and **singly produced VLQs**

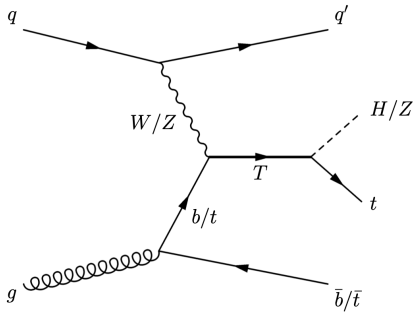
First combination of pair produced LQs, with **significant improvements** over individual searches

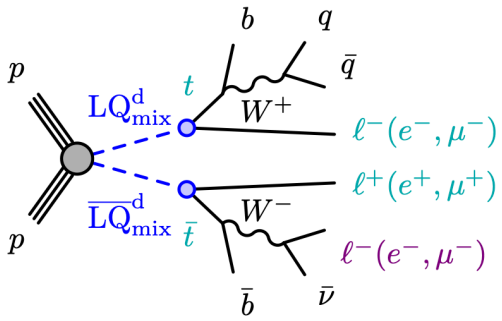
Many opportunities on non-standard production and decays, which are not yet explored as comprehensively

Still great potential for discovery with expected improvements in performance and analysis techniques







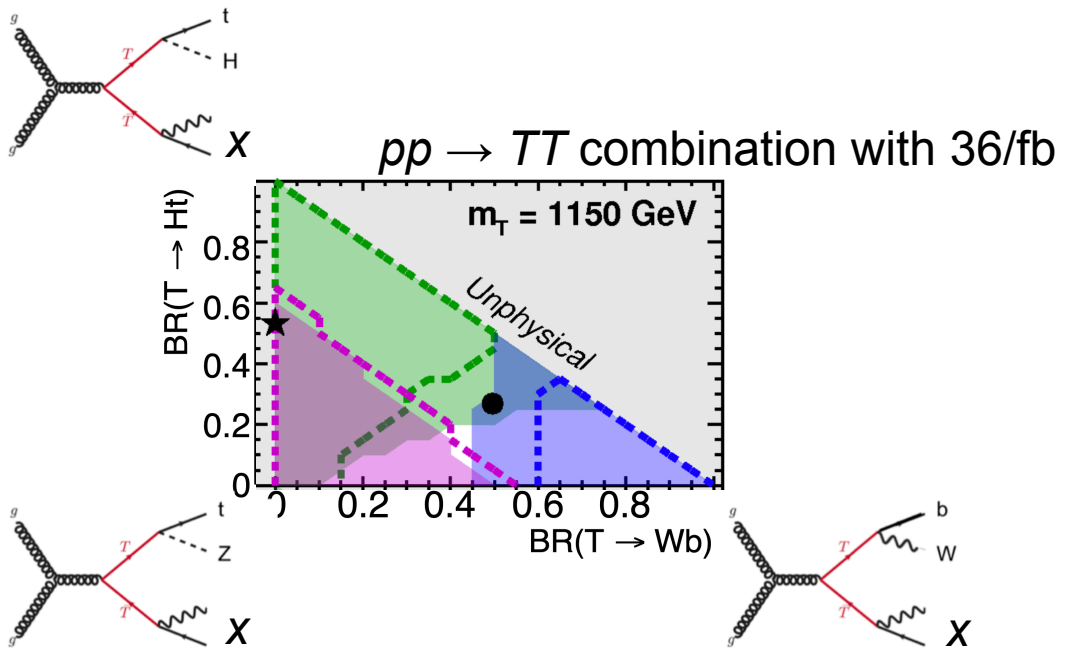


Thank you

VLQ pair production

Overview of ATLAS results

Pair production	Most sensitive decay	
Analysis 36/fb	$T\bar{T}$ decay	$B\bar{B}$ decay
$H(bb)t + X$ [16]	$HtH\bar{t}$	-
$W(\ell\nu)b + X$ [17]	$WbW\bar{b}$	-
$W(\ell\nu)t + X$ [18]	-	$WtW\bar{t}$
$Z(\nu\nu)t + X$ [19]	$ZtZ\bar{t}$	-
$Z(\ell\ell)t/b + X$ [20]	$ZtZ\bar{t}$	$ZbZ\bar{b}$
Tril./s.s. dilepton [21]	$HtH\bar{t}$	$WtW\bar{t}$
Fully hadronic [22]	$HtH\bar{t}$	$HbH\bar{b}$



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